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(57) Abstract

This invention relates to artificial body parts like prostheses, orthoses, implants and parts of dolls, provided with a metal framework, embedded in a completely elastic deformable cover. In order to adjust the posture of such products by means of an externally applied force, these products are provided with a non-elastic component. This component is made by means of using parts of memory metal in the framework, which are not subject to a permanent plastic deformation during shaping, because there is a mechanism of reorientation of martensite variants, which prevents work hardening in the metal. Such composed constructions can be put into a desired posture many times by means of an externally applied force, without fracture or failure occurring in the metal of the framework.

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Transformable structure

The invention relates to a deformable, for example at least locally flexible, pivotal or torsionable structure, comprising a number of discrete or continuous connected and mutual movable elements, which elements are mutually connected by means of a metal positioning element in such a way that the structure maintains a deformation for example a bending or an axial rotation, caused by external forces, after the removal of said forces.

Such a structure can be applied in artificial limbs, as prostheses, orthoses, implants and also in dolls.

In order to adjust the posture at will in said products a not elastic component is present. This component maintains the posture and prevents the back spring action of the elastic cover.

Well known are dolls with elastic polymer limbs, which limbs contain in its axial centre metal threads. These threads are made of a metal which allows very easy plastic deformation, even several times. In practice this causes after a certain number of deformations such changes in the material structure that the resistance against deformation increases and finally results in fracture and failure. This is caused by the so-called strain related work hardening in the material, which reduces the number of sliding planes in the material. Because of this, the number of possible deformations is in principle limited.

In hand prostheses for hand amputees until so far no satisfactorily solution has been found for providing in functional artificial fingers who can hold objects. Although electrical driven hand prostheses do exist, their highly complex construction is at least one drawback and they can not always be used.

The invention has in view to improve a known deformable structure in such a way that the number of possible deformations is not longer limited, at least not limited because of the limited number of deformation cycles of the positioning element or positioning elements.

For this, the invention offers a deformable structure of the said type, which shows the feature that each positioning element consists at least partially of a material which can be

deformed without plastic deformation and which material is not subjected to reinforcement because the material endures under deformation a martensitic reorientation.

The stability of the structure in a by external forces deformed position, allows to load the structure externally without additional deformation Obviously, the external applied forces must be lower than the critical load which causes an additional deformation of the structure.

This can be achieved by using memory metal in a specific martensitic state, in which state no transformation towards the high temperature austenitic state occurs.

In the low temperature state, the memory metal has mainly a martensitic structure which allows very easy deformation up to a strain of 8%, without an elastic back spring effect.

When deformed, there is, in opposite to conventional metal behaviour, no plastic deformation but a martensitic reorientation of the material, induced by the external load.

This transition or reorientation of one martensitic state into another martensitic state takes place by twinning and is fully reversible. Experiments have shown that these metals can be deformed millions of times without fracture and failure because of strain related work hardening.

It is desirable that the memory metal is used in this application at a temperature which is below the martensitic to austenitic transformation temperature range, otherwise this transformation will cause a change of the positioning element because of the memory effect of the material. However, warming up of the material into the austenitic state can be used to restore the original positioning and posture of the material if the positioning element has been deformed severely and can not be bent back into its original state. Because of the memory effect, the positioning element will come back in the original position. once programmed by the heat treatment. When it is back at the environmental temperature the positioning element can be deformed easily again. The memory metal can be one of a large number of types but the most practical are the so called binary Titanium-Nickel alloys or ternary alloys of Ti, Ni and a third element as for example Si, Cu, Zr, Hf, Pd, Au, or Pt, in which the third element is responsible for an increase in the transformation temperature. Such a metal will be in the martensitic state at room temperature.

All said materials are polycristalline materials but there are also monocrystalline materials like the alloy Cu-Al-Ni, which is excellent deformable. In the deformed state, the material has an acceptable stability because the critical load, which results in reorientation of the martensite, is in the range of for example 50 to 150 MPa. External loads which are lower than this critical load only result in a small elastic deformation of the construction. An artificial prosthetic hand, which is constructed on this basis, can be used to hold objects of different sizes by adjusting the shape of the hand with respect to the shape of the object, as for example the handle bar of a bicycle. Besides prostheses for amputees, also orthoses who serve to give an external support of human limbs in disorder, can be constructed on this basis.

Another application is the construction of implants, who serve as an internal support or replacement for functions or parts of the human body.

Another application is the use in dolls in order to provide the dolls with joints or fingers or in general limbs, which can be adjusted in any desired position.

In the sound human hand, motion is only possible in the joints which are mutually connected by bony elements, which are rigid structures. The invention offers a good imitation of the human hand, by such an adaptation of the deformable structure and/or the elastic cover, that deformation is only possible at specific positions. For this, the intermediate parts of the deformable structure must possess a different and larger stiffness, which can be provided in several different ways.

For the intermediate parts different materials can be used, or metal reinforcements can be added to the structure, placed in nearly located savings in the cover material. In that case the positioning elements can have the same uniform deformability, but nevertheless the combined structure will still be forced by external loads in a natural posture.

Of course another possibility is to have a homogeneous cover and to achieve the differences in deformability in the deformable structure in one of the following ways. One could give the memory metal at distinctive positions a different geometry, for example by partial removal by grinding, which will locally reduce the resistance against bending.

Another approach is to use memory metal at the joint locations and for the intermediate parts of the structure a different metal, which can be bonded, welded or clamped to the memory metal.

It is also possible to use memory metal, which has been subjected during the production process to a certain amount of cold deformation, which hampers or restricts the deformability.

The material only shows the property of repeatable deformability after being subjected to a heat treatment. The temperature of this treatment and its duration influences the final behaviour of the memory metal. By applying the heat treatment only locally at the required joint position, a positioning element is obtained with deformable parts or joints and relatively not deformable parts.

It will be clear that many variations do exist in which the deformability is locally influenced by several means.

The essence of the invention is that a positioning element is used, which is based on the large deformability of memory metal at the martensite-martensite transition, eventually in combination with an elastic deformable cover material.

The invention will be further elucidated in the following on the basis of embodiment with reference to the drawings.

In the drawings show:

figure 1 a view of an arm with an orthosis, provided with positioning elements wi memory metal;

figure 2a a bendable rod;

figure 2b a view of a penis, provided with an adjustable internal rod, in an erected position;

figure 2c the same penis, but now in the rest position.

figure 3 a hand prosthesis, provided with positioning elements, which can be put into any desired posture by external means;

figure 4 a length cut through a finger prosthesis, provided with a deformable positioning wire;

figure 5 a cross section of a prosthetic finger;

figure 6 an example of a positioning wire with variable geometry in length direction;

figure 7 an example of a positioning wire with variable stiffness in length direction.

Figure 1 shows an arm 1, of a patient with an external orthosis 2, which is attached to arm, wrist and fingers by means of bands 3. The bands further maintain the posture of a positioning wire 4, which is at least partly made of a memory metal, of which the external shape can be altered at will by means of bending or torsion.

Figure 2a gives an example of a bendable implantable rod 5, existing of an elastic cover 6 that surrounds a memory metal core wire 7. Such an element can be placed into the body to support a specific function.

Figure 2b gives an example of a rod 5, that has been placed into the swell body of a penis 8, to remedy erection problems. With the hand the penis can be put into the erection position.

Figure 2c gives the same penis 8, which now has been put into the rest position by means of bending rod 5 by hand.

Figure 3 gives a hand prosthesis 9, existing of an elastic polymer cover 10 surrounding a framework made of the following parts: More or less rigid phalanges 12 are mounted on a bendable memory metal strip or wire 11. The memory metal elements 11 of the four fingers and the thumb come together into a common mounting block 13, which is completely surrounded by a cover 10. The place of the phalanges 12 on the elements 11 has been chosen

in such a way, that the external shape of the hand prosthesis 9 looks as natural as possible, which is caused by the local bending of the memory metal elements that work as limbs.

Figure 4 gives an example of an alternative construction in a finger prosthesis 14, in which the place of bending is defined in a different way. The polymer cover of memory metal element 15 has been made of a material which has a stiffness that varies along the length direction. At places where the finger is supposed not to bend, like at the bones in a natural finger, the polymer cover 16 is relatively rigid and thus it does not admit bending, even when the underlying memory metal is bendable. However, at the places of the limbs 17 the polymer cover can be elastically deformed easily, which implies that in this way a finger has been made with a natural performance.

Figure 5 gives a cross section view A-A of the finger in figure 4, where the geometry of the memory metal element 15, embedded in the elastic polymer cover 17, has been chosen in such a way, that the stiffness along the axis of bending x-x is much smaller than along axis of bending y-y. In this way it is possible to prevent the possibility that the finger can be placed into an unnatural direction of bending.

Figure 6 gives a memory metal element 18, that got a variable stiffness in length direction by means of adaptation of the geometry. Parts a and c are relatively stiff, but the central zone b has a different cross section and is therefore easier to bend. In the central zone the memory metal can be either rolled to a smaller thickness, partial ground away or machined in a different way.

Figure 7 gives another embodiment of a memory metal element 19, with zones a and c, which are more rigid than central zone b, because in the central zone the temperature at which the heat treatment of the memory metal has been executed differs from the heat treatment temperature of zones a and c. If during the production process the memory metal is work hardened by cold working with a reduction of for example 20 %, the stiffness will be greater than in the case when it has been annealed. The mechanism of reorientation of martensite variants can only work optimal after a heat treatment of the work hardened material.

By a proper choice of the annealing temperature and also the annealing time it is possible to achieve a variation of the stiffness at specific places in the memory metal element. The parts that have relatively stiff are not heat treated or eventually heat treated at a lower temperature or heat treated during a shorter period of time (or a combination of lower temperature and shorter time) than the parts, which have to be well deformable later. This can be achieved by clamping the part that has to be made bendable between two electrical connecting-terminals and then heat it by means of direct resistance heating. The temperature of the heated part can be checked with a thermocouple or a temperature indicator, which changes colour as soon as it reaches the desired temperature. Another method of heat treatment is by means of a flame, hot air or a hot liquid.

In the described drawings and text only some examples of different embodiments have been given. It may be clear, that also different possibilities of application according to the principles of the invention are claimed as being part of this invention. This also counts for adjustable prostheses, implants, orthoses and parts of dolls that have not been mentioned in the description, like for example neck, back, shoulder, elbow, wrist, hip, knee, ankle, foot and toes.

CLAIMS

1. Transformable, for example at least locally bendable, pivotal or torsionable structure, comprising: a series of mutual movable elements that have been linked in a discrete or continuous way, which elements have been interconnected by means of a metal positioning element in such a way, that the structure maintains a transformation in shape that is caused by external applied forces, like for example a bending, a pivotal displacement of the mentioned elements, or a torsion, after the removal of the mentioned external forces,

characterized in that

it exists at every positioning element at least partial from a material that can be deformed without plastic deformation and which is not subject to work hardening, because it undergoes a martensitic reorientation during shape change.

2. Structure as claimed in claim 1,

characterized in that

the structure is oblong and the or each positioning element has an oblong shape, with a length direction that corresponds more or less with the length direction of the structure.

3. Structure as claimed in claim 1,

characterized in that

the reorientation in the metal is a martensite to martensite transformation caused by twinning.

4. Structure as claimed in claim 2,

characterized in that

the metal exists from a shape memory alloy with a transformation temperature range for the transformation from martensite to austenite, which is above the ambient temperature of use.

5. A structure as claimed in claim 3,

characterized in that

the structure can be deformed on a specific first place or into a specific first direction easier than on a specific second place or into a specific second direction, in such a way, that

the shape change preferably takes place on the first place or into the first direction, when said external forces are applied.

6. Structure as claimed in claim 4,

characterized in that

the parts which can easier be deformed exist from a different material than the parts which can be deformed more difficult.

7. Structure as claimed in claim 4,

characterized in that

the geometry of the parts which can easier be deformed differs from the geometry of the parts which can be deformed more difficult.

8. Structure as claimed in claim 4,

characterized in that

the preceding heat treatment of the parts which can easier be deformed is applied during a longer period of time or at a higher temperature than the preceding heat treatment of the parts which can be deformed more difficult.

9. Structure as claimed in claim 4,

characterized in that

at least the parts which can easier be deformed have been made from an intermetallic compound of Ni and Ti.

10. Structure as claimed in claim 4,

characterized in that

at least the parts which can be easier deformed have been made from an intermetallic compound of Ni, Ti, and at least one of the elements Si, Cu, Zr, Hf, Pd, Au or Pt.

11. Structure as claimed in claim 4,

characterized in that

at least the parts which can easier be deformed have been made from a single crystal.

12. Structure as claimed in claim 10,

characterized in that

the single crystal has been made from the elements Cu, Al and Ni or from Cu, Zn and Al.

13. Structure as claimed in claim 2,

characterized by

an elastical cover, embedding an oblong positioning element.

14. Structure as claimed in claim 13,

characterized in that

the cover consists of parts which are placed in adjacent order in length direction and which have different compliancies.

15. Structure as claimed in claim 14,

characterized in that

said parts are made from different materials.

16. Structure as claimed in claim 14,

characterized in that

said parts have different geometries.

17. Structure as claimed in one of the preceding claims,

characterized in that

the structure is meant to be used as an orthosis, prosthesis or implant.

18. Structure as claimed in one of the claims 1-16,

characterized in that

the structure is meant to be used as at least a part of a doll with limbs which have an adjustable posture.

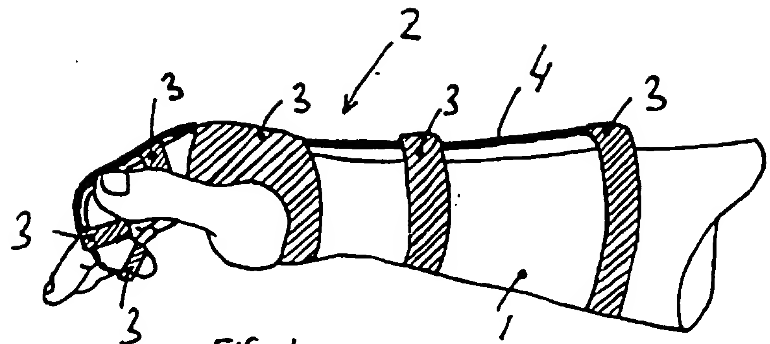

FIG. 1

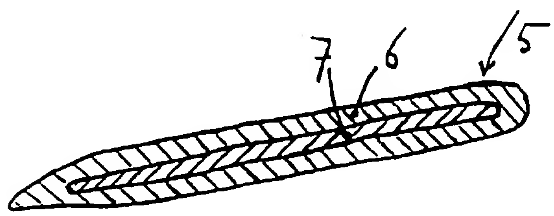

FIG. 2a

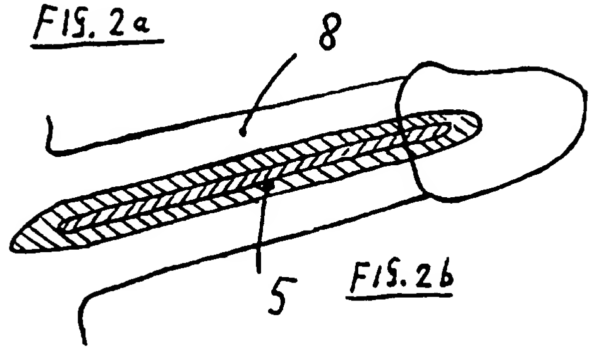

FIG. 2b

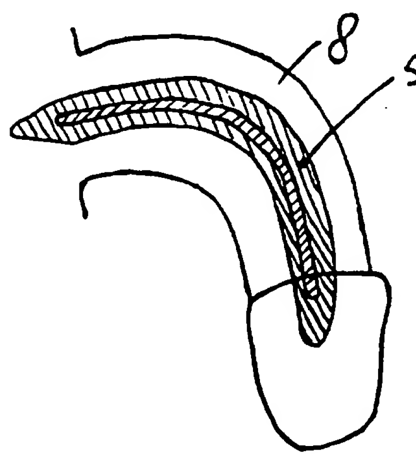

FIG. 2c

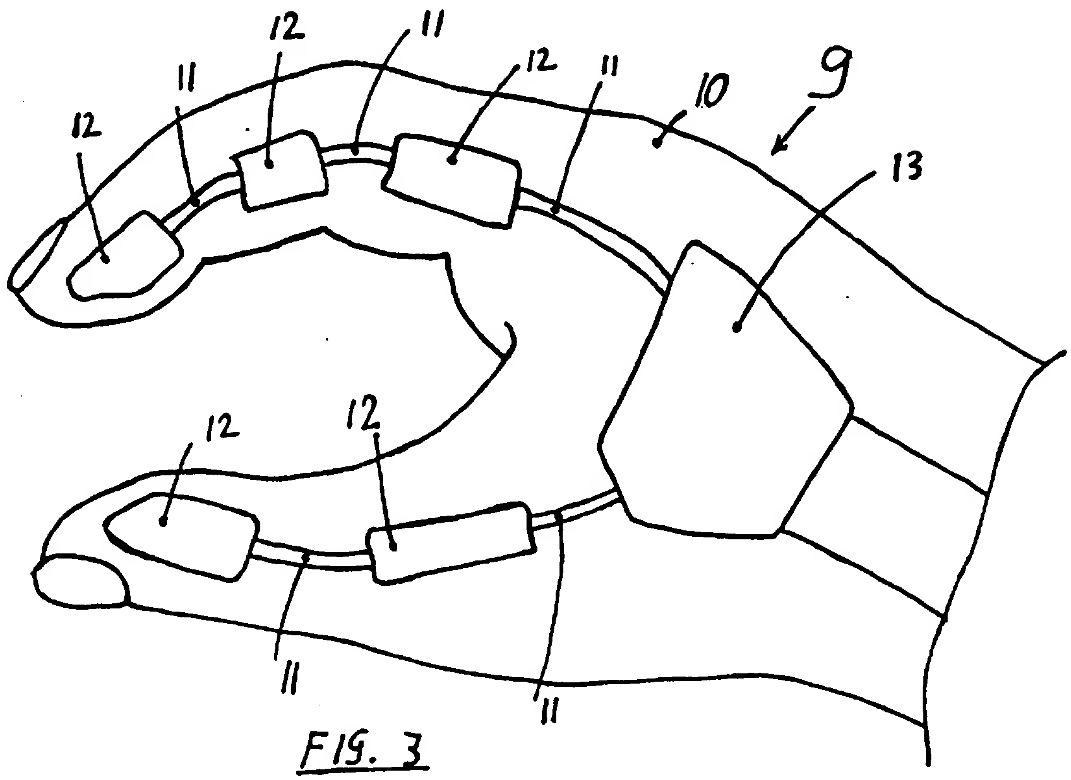

FIG. 3

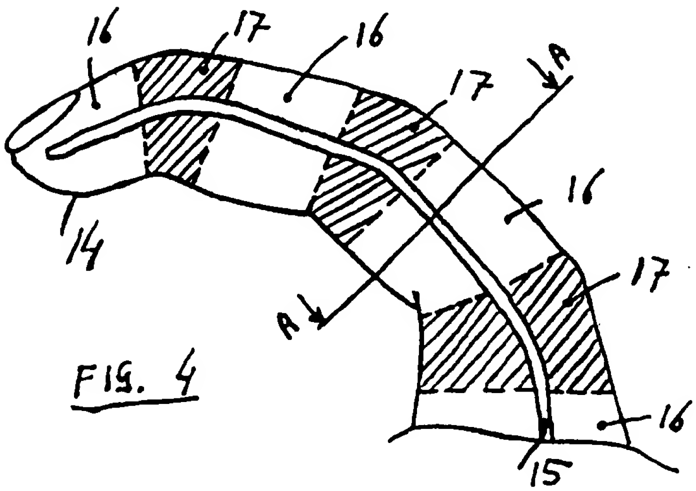

FIG. 4

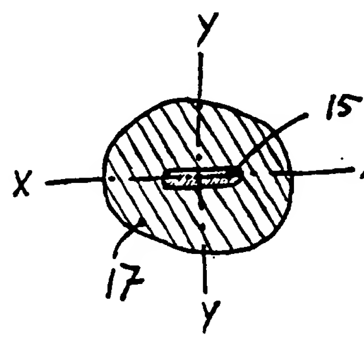

FIG. 5 (A-A, FIG. 4)

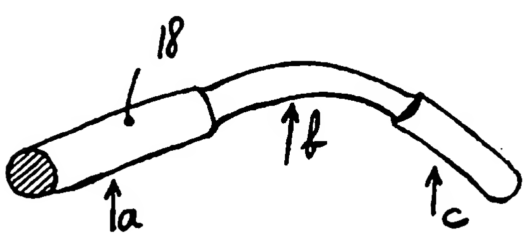

FIG. 6

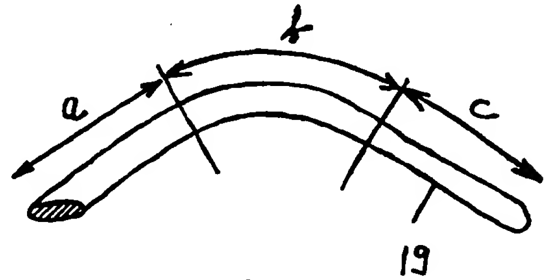

FIG. 7

INTERNATIONAL SEARCH REPORT

Int ional Application No
PCT/NL 96/00182

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F16C11/12 A61F2/26 A61F2/58 A61F5/01 A63H3/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61F F16C A63H F16F G02C A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP,A,0 146 317 (KRUMME) 26 June 1985 see the whole document ---	1-12 13-18
Y	US,A,2 134 974 (HURWITZ) 1 November 1938 see claim 1; figures 1-4 ---	13-18
X	PATENT ABSTRACTS OF JAPAN vol. 009, no. 206 (M-406), 23 August 1985 & JP,A,60 065906 (WASEDA DAIGAKU), 15 April 1985, see abstract ---	1
A	EP,A,0 470 660 (COOL) 12 February 1992 ---	
P,X	EP,A,0 679 377 (TOKIN) 2 November 1995 see abstract; figure 1 -----	1,17

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Date of the actual completion of the international search	Date of mailing of the international search report
31 July 1996	30.08.96

Name and mailing address of the ISA	Authorized officer
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Information on patent family members

Int ional Application No
PCT/NL 96/00182

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